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Abstract

A-PHOENIX is a new compact hybrid electron cyclotron resonance ion source (ECRIS) using a large permanent magnet hexapole (1.92 Tesla at the magnet surface) and High Temperature Superconducting Solenoids (3 Tesla) to make min-|B| structure suitable for 28 GHz CW operation. The final assembly of the source was achieved at the end of june 2007. The first plasma of A-PHOENIX at 18 GHz was done on August the 16th 2007. The technological specificities of A-PHOENIX are presented. The large hexapole builded is presented and experimental magnetic measurements show that it is nominal with respect to simulation. A fake plasma chamber prototype including thin iron inserts showed that the predicted radial magnetic confinement can be fulfilled up to 2.15 Tesla at the plasma chamber wall. Planning of experiments scheduled until end 2008 is presented.

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1 A-PHOENIX Features

1.1 Hexapole

The A-PHOENIX preliminary design has been previously presented in [1]. The final detailed drawings were achieved in june 2006 and mechanical parts were ordered since this date. The large A-PHOENIX hexapole involves huge magnetic forces between magnets and also toward the surrounding mechanical parts holding it. Dedicated mounting tools were designed and built in order to safely mount the 468 permanent magnets contained inside. The magnets were provided by Vacuum Schmelze company [2]. Minimum values concerning coercivity and magnetization were asked to the company in order to guarantee a safe hexapole behavior up to 40°C. The final hexapole design is shown figure 1. The central hexapole ($|z|<120$ mm, $36<r<200$ mm) is composed with three axial magnet layers and three radial magnet layers. These magnets were bought directly pre-glued to form 240 mm length magnets, making thus 1/36 of a single Hallbach type cylindrical hexapole layer. The total number of magnets inside this first hexapole is $36\times3\times3=324$. Random unsticking of these pre-assembled magnets during the mounting generated strong unexpected axial explosive forces that created difficulties and delays for mounting the hexapole. The maximum explosive force due to magnet unsticking was calculated to be 1,4 kN, making it worth dangerous during some stage of the assembly. Tools were then modified to take into account this new force. At each end of this main hexapole is located a smaller lateral hexapole ($120<|z|<220$ mm, $36<r<56$ mm) to insure radial magnetic continuity up to the axial magnetic mirror end. Even though this lateral hexapole is small, the high magnetic field gradient seen by the magnets required to use two cylindrical layers [3]. Both lateral hexapoles contains $2\times36=72$ magnets. The principle of the mounting is described as follow. The outer metallic cylinder part holding the main hexapole magnets was filled up with brass mechanical parts having the same geometry as the pre-glued magnets. The inner bore of the hexapole was filled with a massive brass cylinder. At each end of the hexapole were located thick rotation free aluminum flanges drilled with holes machined by spark erosion and having the cross section shape of the magnets to be introduced. The hexapole assembly consisted to push magnets inside, one by one, through the flange holes, chasing out consequently one mechanical brass part through the opposite flange hole. The force to push magnets inside was achieved with a press. In this configuration, any axial, radial and azimuthal magnet move was avoided. In case of a magnet unsticking, the axial force was held by the press, but the magnet has to be chased out, then cleaned and glued again while being pushed again inside the hexapole. 24 hours were then necessary to wait for the epoxy glue to dry while the magnet was kept into compression.

The main hexapole magnetic field has been measured with a Hall probe located in the plasma chamber. The radial magnetic field induction is 1.55 T at the hexapole center, on the plasma chamber wall, while the simulation predicted 1.58 T. This little difference is due to the special request to the magnet company to deliver preferably higher coercivity magnets than normal ones, inducing a consequent lower magnetization level. Nevertheless, the measurements are in good agreement with the simulation program. This radial field is suitable for high performance 18 GHz operation.

1.2 Special Plasma Chambers

For 28 GHz operation, it is preferable to reach 2 T radial confinement. Special thin plasma chamber designs including pure iron parts have been studied by simulation [1]. This original concept is derived from former studies made at Jyvaskyla [4],[5]. The final design of such a plasma chamber is proposed on figure 2. A special care was taken for the water cooling system design. It is composed of 6 independent circuits. Water first flows along a pole and then goes back in spaces where no plasma heat is expected. The inner and outer cylinders are made with stainless steel. Six iron plates (1 mm thick and 6 mm wide: see middle gray plates on figure 2) are welded into the thickness of the outer plasma chamber cylinder. These pure iron plates will be brazed under secondary vacuum at high temperature using a nickel-based brazing alloy. On the inner cylinder, the iron plates are 1 mm thick and 2.5 mm wide (dark plates on figure 2). There, the welding will be achieved with a laser technique that guarantees a low out gassing level of the welded parts in the vacuum. Electronic bombardment technique was first foreseen for the inner cylinder, but was abandoned because the pure iron magnetization induces an electron beam deviation that cannot insure a reliable welding. In order to test the validity of the simulation study, a special fake plasma chamber has been built including inner and outer pure iron plates. The radial magnetic field was measured in the A-PHOENIX plasma chamber as near as possible of the chamber wall with and without iron plates. The experimental measurement is plotted in figure 3 along with the predicted plots. The experimental magnetic field is 1.5% lower than the simulated one, but it enables to reach 2.15 T at the plasma chamber wall. Thanks to this experimental confirmation, two special plasma chambers will be built fall 2007: one with only outer iron plates to reach 1.8 T of radial magnetic field and another with both inner and outer iron plates to deliver 2.15 T. So the experiments will enable to test A-PHOENIX performance with 1.55, 1.8 and 2.15 T radial confinements.

1.3 Axial Coils

The magnetic mirrors of the A-PHOENIX source are obtained with the magnetic field established by two High Temperature Superconducting (HTS) coils and a room temperature coil to tune B_{min} magnetic field. LPSC designed and built the quench detection and interlock system of these HTS coils. The specifications of these systems were given by Scientific Magnetics [6] (former Space Cryomagnetics LTD) who designed and built the HTS Coils. The quench protection system is based on the Wheatstone bridge technique to detect any resistive propagating quench occurring in the coil pancakes. The basics of such a system can be found in [7] for instance. The external safety circuit is based on a 0.1 Ohm resistor which is permanently settled in parallel to the coil and its power supply. An electro-mechanic switch is placed between one output of the power supply and the resistor. In case of a detected coil failure, the system opens the switch and the power supply is interlocked. The coil current is then forced to damp inside the resistor. Should the switch fail, or primary electrical power fails, the coil can still be dumped inside the resistor. The injection coil is designed to produce a 3 Tesla axial magnetic field peak in A-PHOENIX. When no current flows inside, the cryorefrigerator and the coil temperatures are respectively 13.8 and 14.7 K. When the coil is magnetized to its maximum (I=168 A), these temperatures become respectively 14.7 and 15.6 K. The AL330 cryorefrigerator capacity curve [8] enables to calculate the heating power increase in the cryostat from 20.2 to 21.8 Watt. The temperature interlock is set on the coil to 20 K. So the experimental temperature safety margin is 4.4 K. Experience with fully superconducting ECRIS has shown that an extra heat generation inside Helium vessel was induced by intense X-rays flux generated by bremsstralhung in the plasma chamber wall [9].

The A-PHOENIX FeNdB hexapole acts as an effective shield that attenuates the X-Ray flux intensity to the HTS cryostats. This point will be checked experimentally with high microwave power injected in the ECRIS. The early A-PHOENIX commissioning didn't show any coil temperature increase due to X-Rays, for a microwave power up to 700 W. A hypothetic 20 K coil temperature triggering interlocks would correspond to an extra heat of ~10 W. This situation in unlikely to happen with Bremsstralhung induced X-rays fluxes.

1.4 Injection vacuum chamber

A-PHOENIX is equipped with a UHV cross at the injection side. A 500 l/s turbomolecular pump is installed there and is suitable to pump the 1.4 litre plasma chamber. The 65 mm diameter of the plasma chamber rendered rather difficult the design of the plasma chamber injection flange. It is nevertheless equipped with standard housings and a photo of the flange is proposed on figure 4. The flange includes a 28 GHz circular oversized waveguide reduced from 32.6 to 25 mm diameter (through a long conical transition), a 18 GHz WR-62 wave guide, a 10 mm diameter bias disk, movable and water cooled, a 11 mm inner diameter tube for gas inlet and a 16 mm one for oven introduction. The flange is also drilled with numerous 4 mm holes to facilitate the pumping of the plasma chamber from the injection cross. In the ECRIS, The vacuum seals are made up with copper gaskets, except for two Viton O-rings located at the end of the main ceramic insulator at the extraction side of the source. The plasma chamber length is 390 mm, so A-PHOENIX is a compact source with 1.25 litre volume. The maximum power density reachable with the 18 GHz 2 kW klystron will be 1.6 kW/l and 12.5 kW/l for the 10 kW/28 GHz klystron.

2 Status of the 18 GHz commissioning, planning and studies foreseen

An incident with one of the A-PHOENIX HTS cryorefrigerator compressor stage delayed severely the starting of the ECRIS commissioning. Finally, the first A-PHOENIX plasma was extracted at 30 kV on August 2007 the 16th. A photo of A-PHOENIX during the commissioning is proposed on figure 5. The few days of commissioning before the conference didn't allow to present innovative results. Up to now, the microwave power is slightly increased for conditioning, so multicharged ion production increases every day. The UHV injection enables a fast low pressure recovery after a source venting, highly faster than with PHOENIX. The A-PHOENIX R&D is supported by the SPIRAL2 project. Hence, the studies foreseen concern the production of A/Q=3 ions with as high intensity as possible for gases up to argon (the Spiral2 LINAC can transport up to 1 mAe beam current). Physics done with stable Ion beams recently become of major interest for Spiral2 and production study of metallic ion beams such as ^{24}Mg,^{48}Ca,^{64}Ni and ^{50}Cr will also be performed in the future. The commissioning will continue at 18 GHz for 3 to 6 months with noble gases and eventually a metallic ion mentioned in the list above. A special dielectric layer adapted to A-PHOENIX will be tested in collaboration with NIPNE [10] and its influence on the high charge state production in the 1 kW microwave range will be explored. Next, the first inox plasma chamber will be changed to the second model boosting the radial field to 1.8 Tesla. The same investigations will then be done at 18 and 28 GHz. Finally, the last 2.15 Tesla plasma chamber model will be installed and experiments will be performed mainly with the 28 GHz gyrotron. Pulsed mode operation study will also be performed, including ionization efficiency measurements. Comparison with higher volume superconducting ECR ion sources results will be very interesting.

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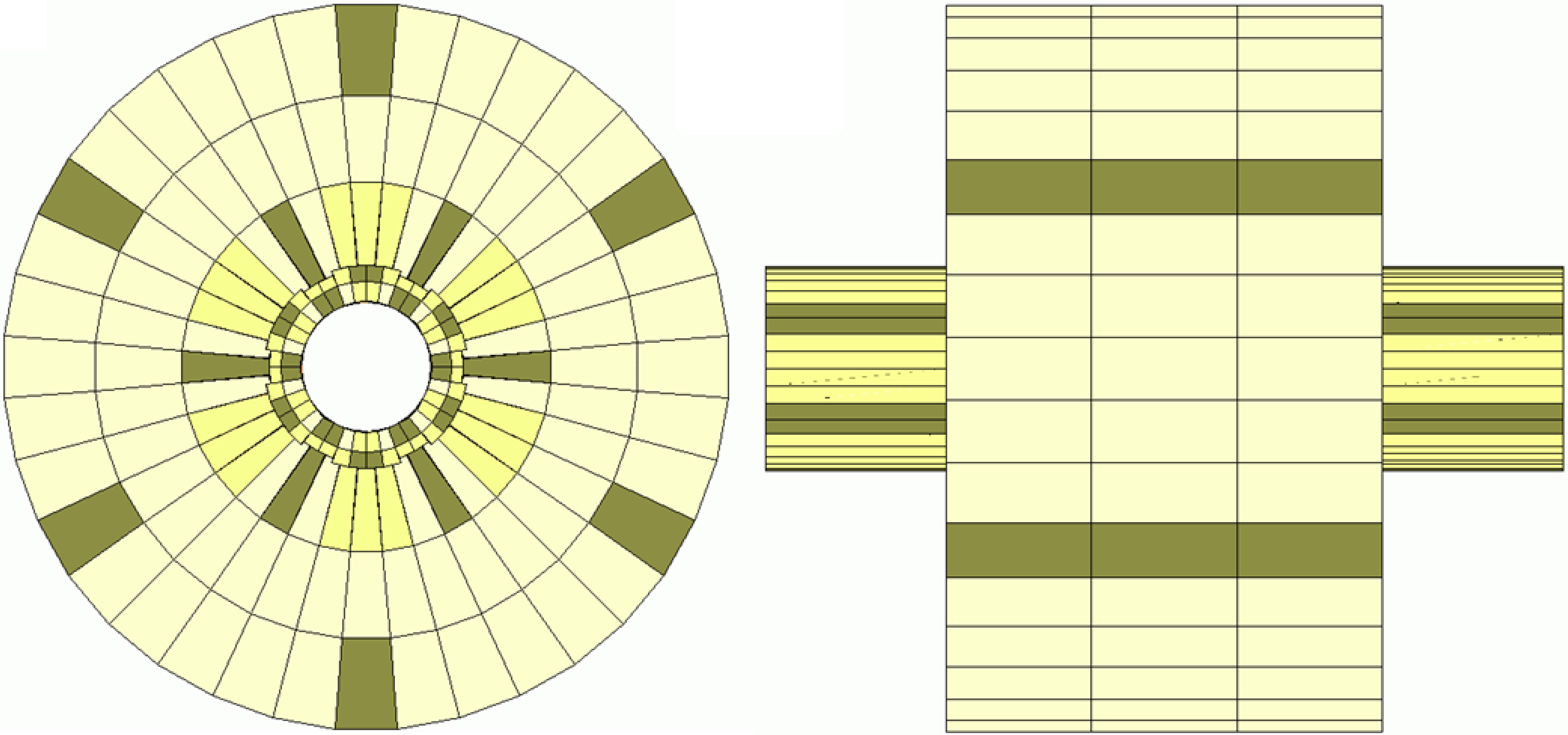
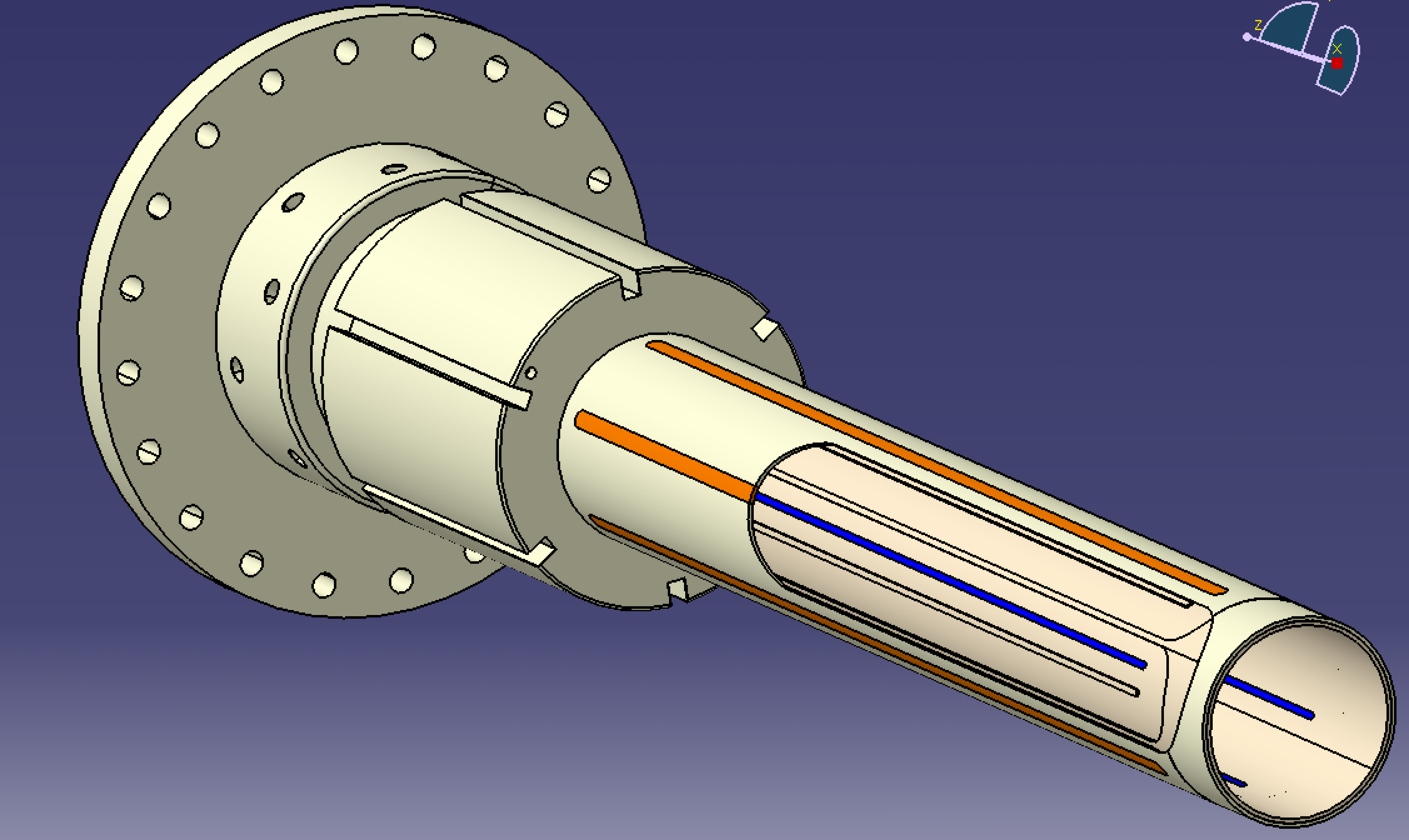
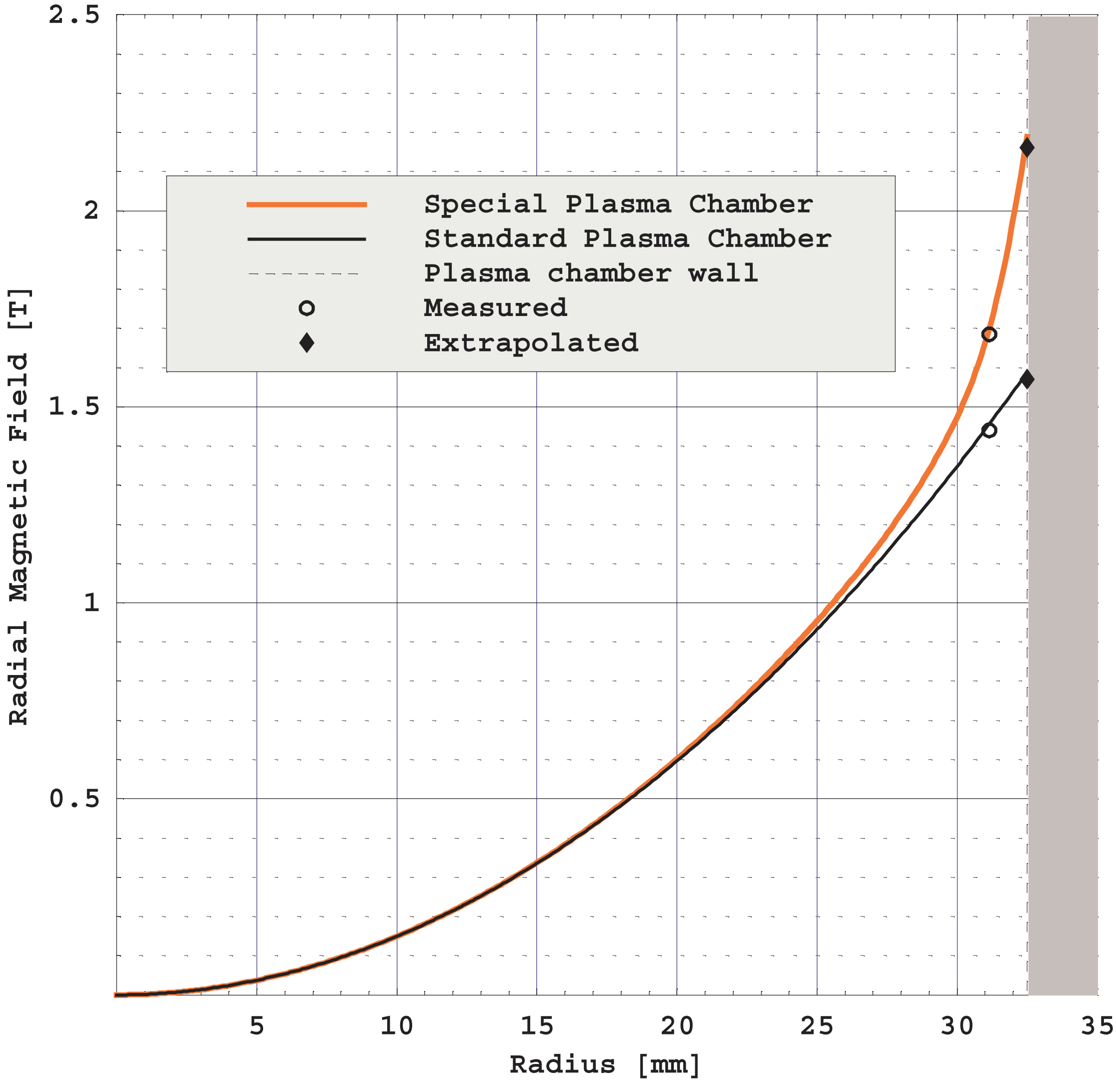
List of figure captions






Special Plasma Chamber
Standard Plasma Chamber
Plasma chamber wall
Measured
Extrapolated
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Radius [mm]
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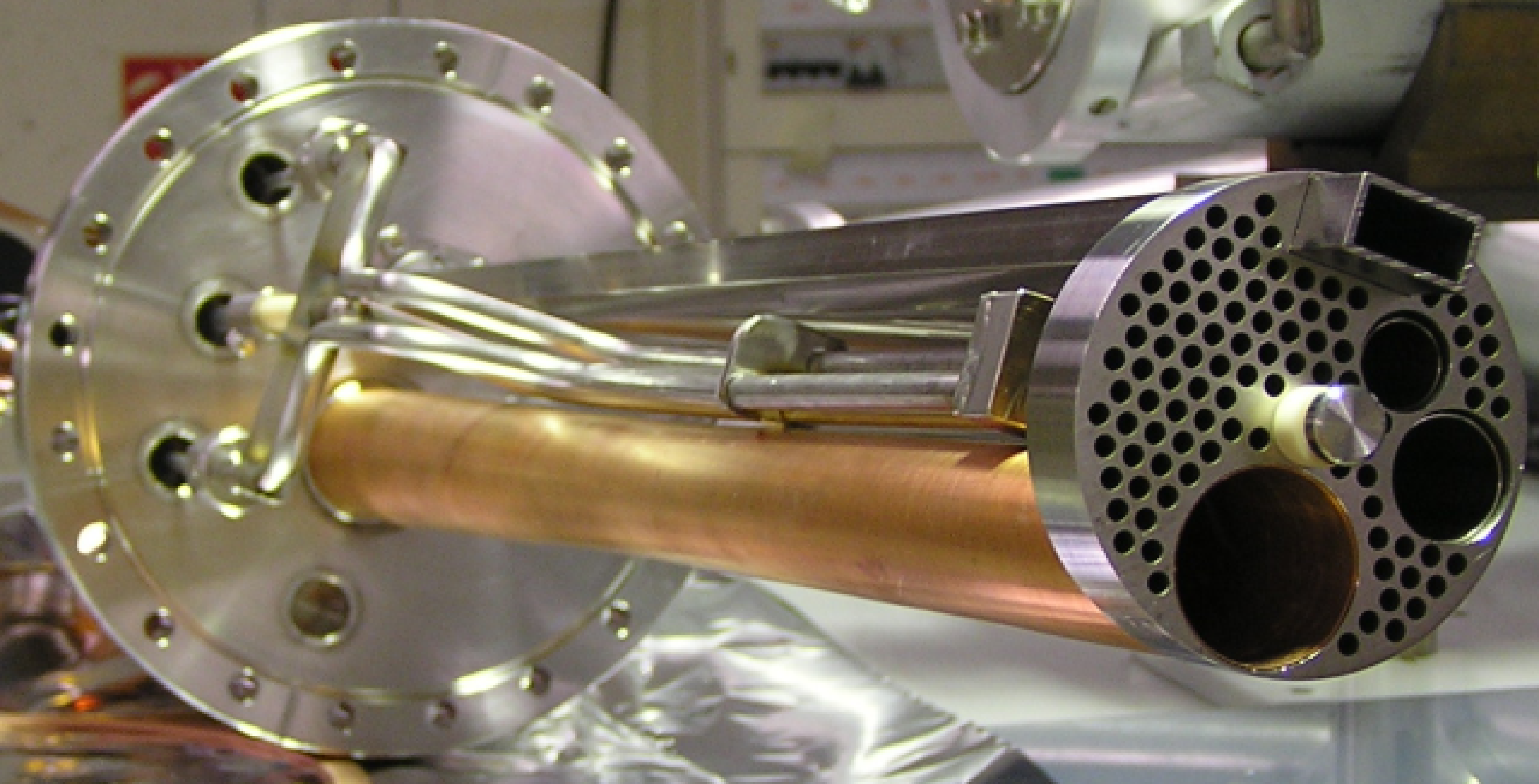
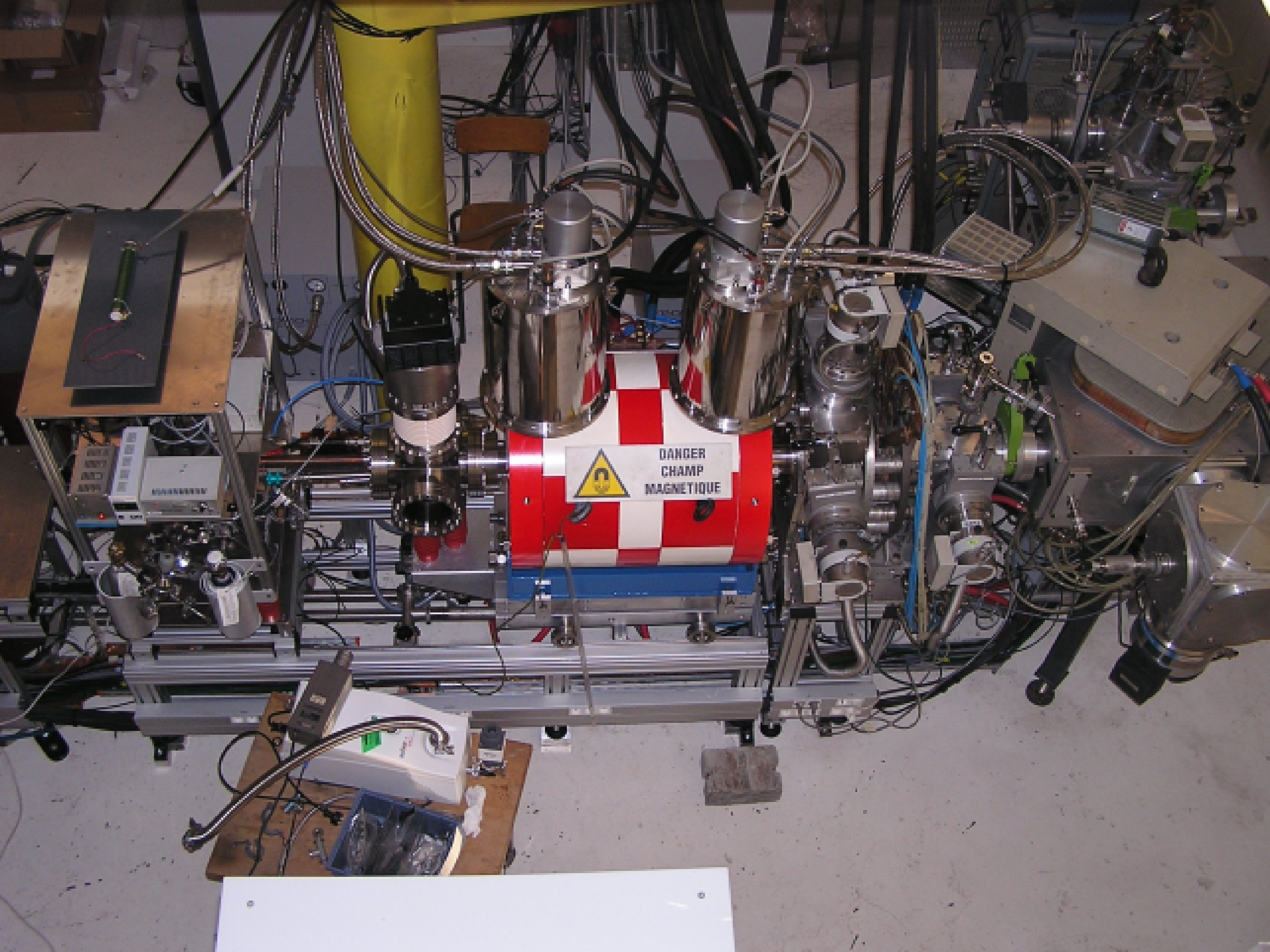
1
1.5
2
2.5
5
10
15
20
25
30
35




DANGER
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